Update on XCAL Activities and Plans

PMM XCAL Team

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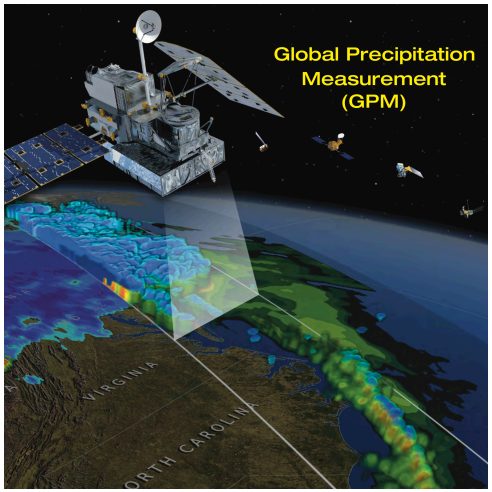

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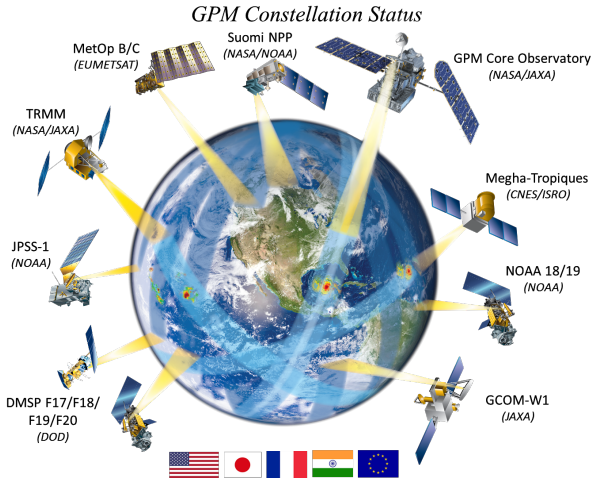


XCAL Activities

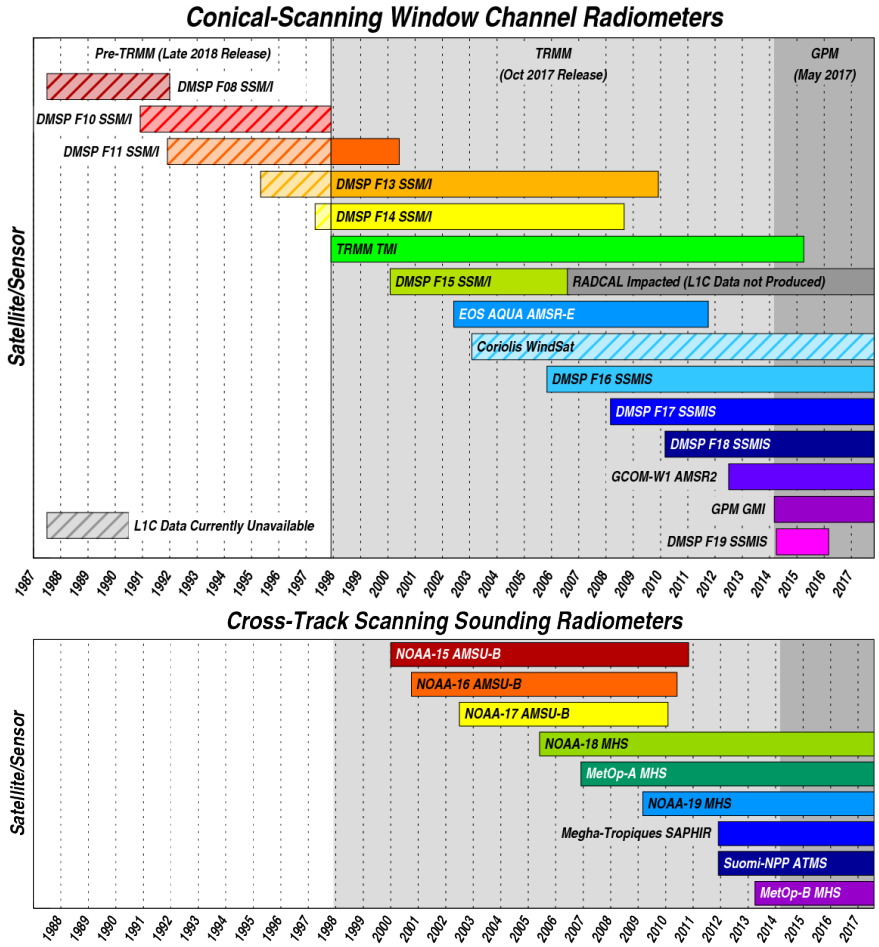
The **XCAL team** is a working group within the Precipitation Measurement Missions (i.e. TRMM/GPM) science team responsible for the **Level 1C intercalibrated brightness temperature files** used as input to the operational precipitation retrieval algorithm for available constellation microwave radiometers.

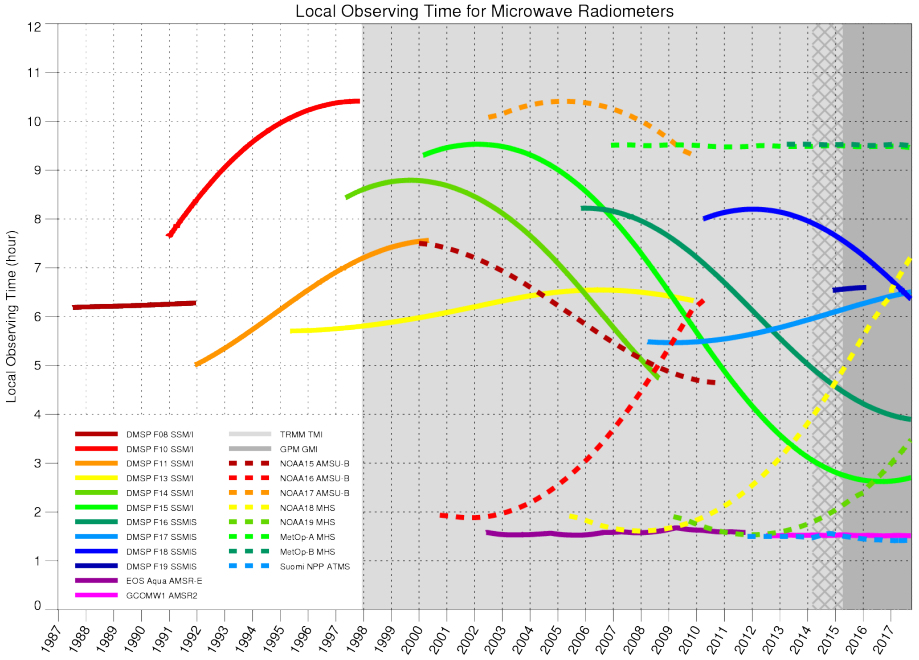
Activities: Following launch of the GPM core satellite in Feb 2014 (Complete, In Progress)

- Assess and update calibration for calibration reference sensor: GPM GMI V05
- Intercalibrate the GPM constellation radiometers
- Update the TRMM TMI Calibration (V8) and intercalibrate to GMI V05
- Intercalibrate the TRMM constellation radiometers
- Extend radiometer constellation back to SSM/I on board DMSP F08 in July of 1987
- Incorporate new (i.e. JPSS1 ATMS, MetOp-C MHS) and additional radiometers (i.e. WindSat)
- Other tasks (quantify uncertainties, improve techniques, RFI, documentation, etc.)

PMM Constellation Radiometers

Intercalibrated L1C Data Availability





GPM Era (V05: May 2017 Release)

- **Imagers (7):** TMI, DMSP F16/F17/F18/F19 SSMIS, AMSR2, GMI
- **Sounders (6):** NOAA 18/19 and MetOp-A/B MHS, SAPHIR, NPP ATMS

TRMM Era (V05: Oct 2017 Release)

- **Imagers (10):** DMSP F11/F13/F14/F15 SSM/I, TMI, AMSR-E, F16/F17/F18 SSMIS
- **Sounders (9):** NOAA 15/16/17 AMSU-B, NOAA 18/19 and MetOp-A/B MHS, SAPHIR, NPP ATMS

Pre-TRMM Era (V05: Late 2018 Release)

- Imagers (5) F08/F10/F11/F13/F14 SSM/I

Future/Other Radiometers

- WindSat (2018 Release?)
- JPSS1 ATMS (Nov 10, 2017 Launch)
- MetOp-C MHS (Oct 2018 Launch)
- MetOp-SG (2021)

TRMM TMI Calibration Updates

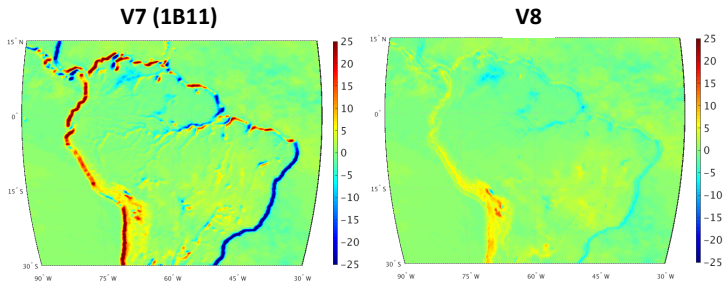
- Updated spacecraft attitude (using PR roll estimates, sun-sensor, and gyro data)
- Updated view-angle offsets (roll, pitch, ½ cone, start angle, timing)
- Updated cross-track bias correction (using both cold and warm scene)
- RFI in cold reflector correction (new)
- TMI antenna-pattern correction (updated)
- TMI reflector emisivities (updated)
- TMI hot-load correction (new)
- TMI reflector temperature (updated)

See talk by Linwood Jones, Wednesday, 1:20pm for more details!

TMI Geolocation and Cross-Track Bias Corrections

Pointing Accuracy

- Spacecraft attitude updated using PR roll estimates, sun-sensor, and gyro data.
- Instrument pitch/roll offsets of 0.08°/0.08° derived from analysis of cross-track bias patterns.
- Updated feedhorn mount offsets for cone angle and azimuth start angle derived based on coastline analysis of yaw 0 versus yaw 180 differences

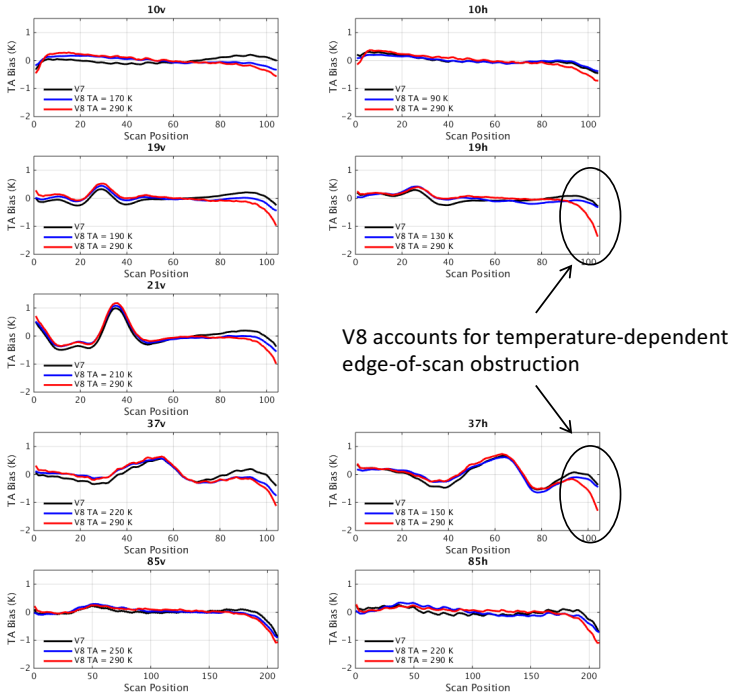


Changes in Cone Angle and Azimuth Start Angle Offsets from V7 to V8

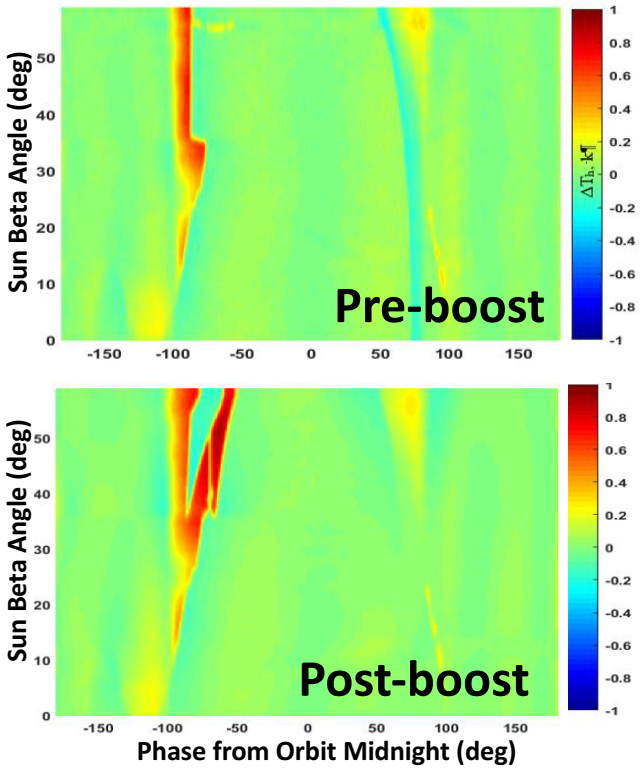
Channel	Cone Angle		Cone Angle Offset for EIA	Azimuth Start Angle	
	V7	**V8**	**V8**	V7	**V8**
10 GHz	49.0	**49.45**	**10v: -0.048 10h: +0.048**	-64.4024	**-63.91**
19, 21, 37, 85 GHz	49.0	**49.28**	**0**	-64.4024	**-64.36**

Cross-Track Bias Correction

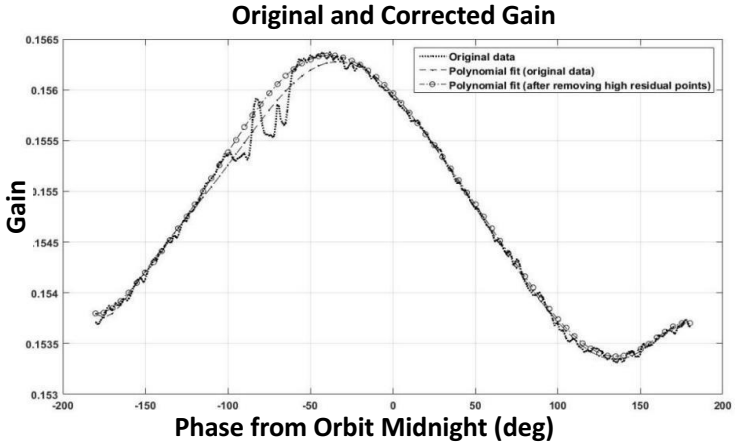
- V7 derives offset from over-ocean TBs and applies it at all scene temperatures
- V8 derives an along-scan correction as a function of temperature, using a linear interpolation between vicarious cold and warm techniques



TMI Hot-Load Correction



A correction for solar intrusions into the TMI hot-load was developed and implemented for V8. The corrections are applied as function of the Sun Beta Angle and Phase from Orbit Midnight as shown above for both pre and post-boost periods.



A polynomial regression was used to remove transient fluctuations in the gain due to solar intrusions into the hot load.

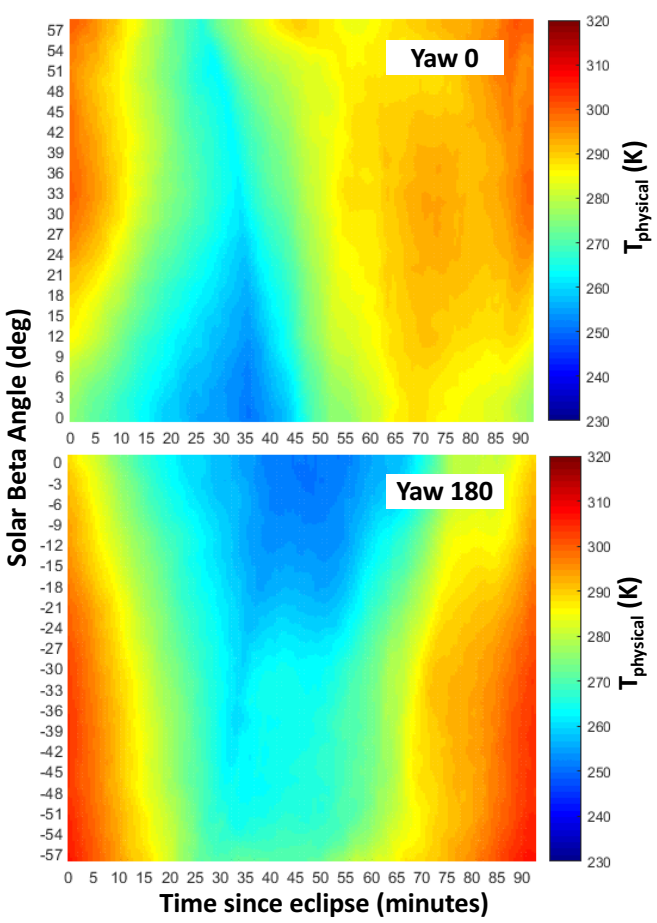
The correction of the hot load temperature (ΔTh):

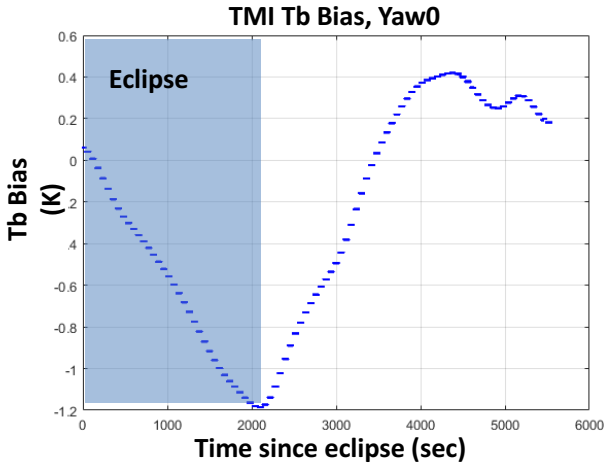
- $T_{h-cor} = G_{fit}(C_h - C_c) + Tc$
- $\Delta Th = T_{h-cor} - T_h$

Results depend on the solar array position and the spacecraft altitude

1. Solar array tracking ±130° (1 year)
2. Solar array tracking ±50° (2.7 years)
3. TRMM boosted (~1 year)
4. Feathered solar array (13 years)

TMI Emissive-Antenna Correction





- After launch it was discovered that the TMI has an emissive main reflector
- This results in a time-varying radiometric calibration error of ±0.75K over one orbit and ±1.5K over seasons for all channels

  $Tb_{measured} = (1- \varepsilon)Tb_{scene} + \varepsilon T_{physical}$
  ε is the reflector emissivity (~0.03 -> 3%)
  Tb_{scene} is the "true" Tb of the scene
  $T_{physical}$ the reflector temperature

- Emissivity values for each channel were derived using data from deep-space calibration maneuvers
- The physical temperature of the reflector was then derived as a function of solar beta angle and time since eclipse (plots on left) for Yaw0 and Yaw180 spacecraft orientations.

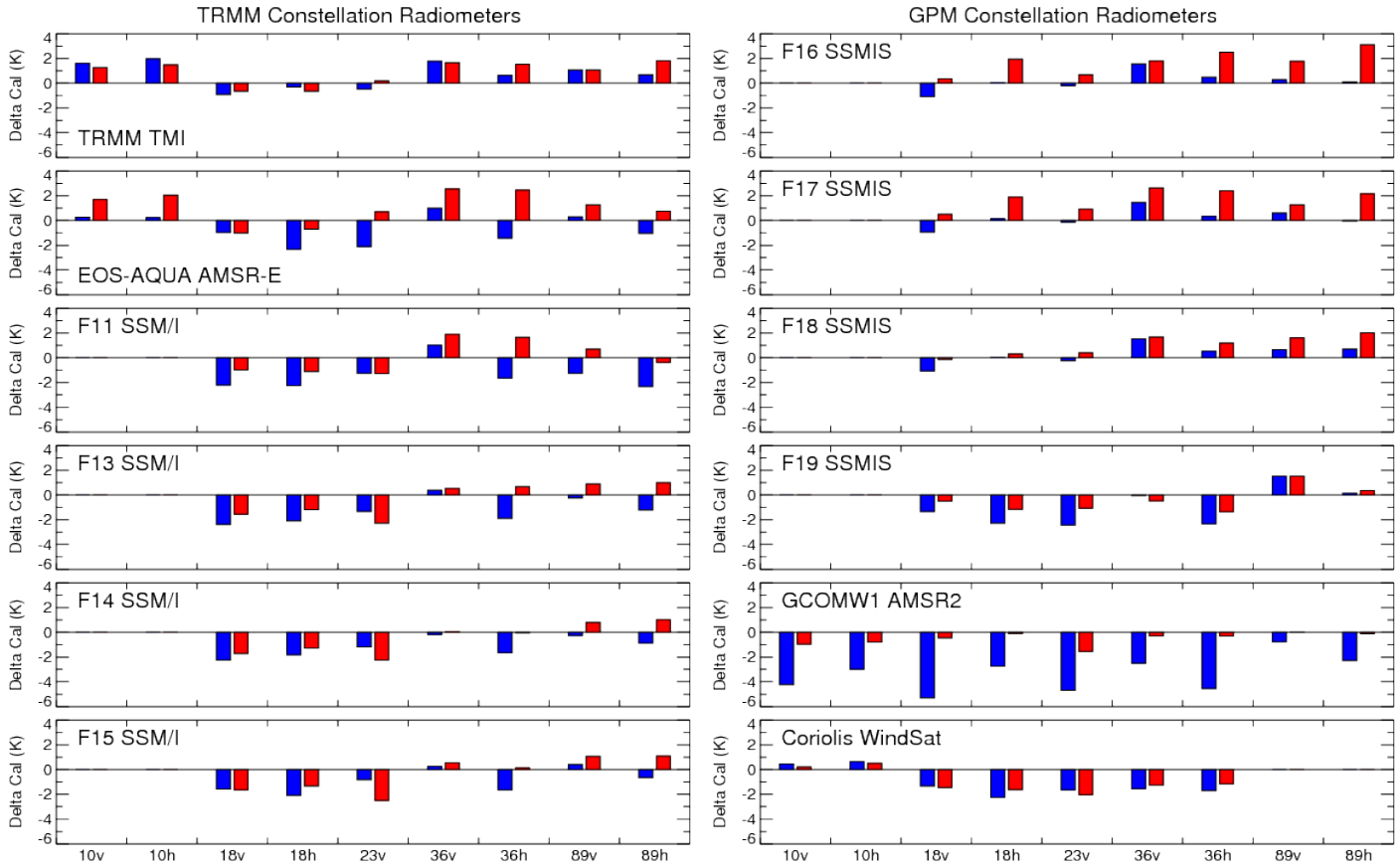
TRMM/GPM Radiometer Constellation

Research and Operational Sensors with Different Capabilities and Calibrations

Satellite (Sensor)	Imager/ Sounder	6-7 GHz	10 GHz	19 GHz	23 GHz	31-37 GHz	85-92 GHz	150-166 GHz	183 GHz
GPM GMI (Calibration Reference)	**Imager**		**10.65vh**	**18.7v/h**	**23.8v**	**36.64v/h**	**89.0v/h**	**166v/h**	**183.31±3, 7**
TRMM TMI	Imager		10.65v/h	19.35v/h	21.3v	37.0v/h	85.5v/h		
EOS AQUA AMSR-E	Imager	6.925v/h	10.65v/h	18.7v/h	23.8v/h	36.5v/h	89.0v/h (A) 89.0v/h (B)		
GCOM-W1 AMSR-2	Imager	6.925v/h 7.3v/h	10.65v/h	18.7v/h	23.8v/h	36.5v/h	89.0v/h (A) 89.0v/h (B)		
DMSP F08, F10, F11, F13, F14 and F15 SSM/I (6)	Imager			19.35v/h	22.235v	37.0v/h	85.5v/h		
DMSP F16, F17, F18, F19 SSMIS (4)	Imager			19.35v/h	22.235v	37.0v/h	91.655v/h	150h	183.31±1, 3, 6.6
NOAA 15, 16 and 17 AMSU-B (3)	Water Vapor Sounder						89qv	150qv	183.31±1, 3, 7qv
METOP A/B, NOAA 18/19 MHS (4)	Water Vapor Sounder						89qv	157qv	183.31±1, 3qh 190.31qv
Suomi NPP ATMS	Water Vapor Sounding				23.8qv	31.4qv	88.2 qv	165.5qh	183.31±1.0, 1.8, 3.0, 4.5, 7.0qh
Megha-Tropiques SAPHIR	Water Vapor Sounder								183.31±0.2, 1.1, 2.8, 4.2, 6.8, 11qh

TRMM/GPM Radiometers Calibration Differences

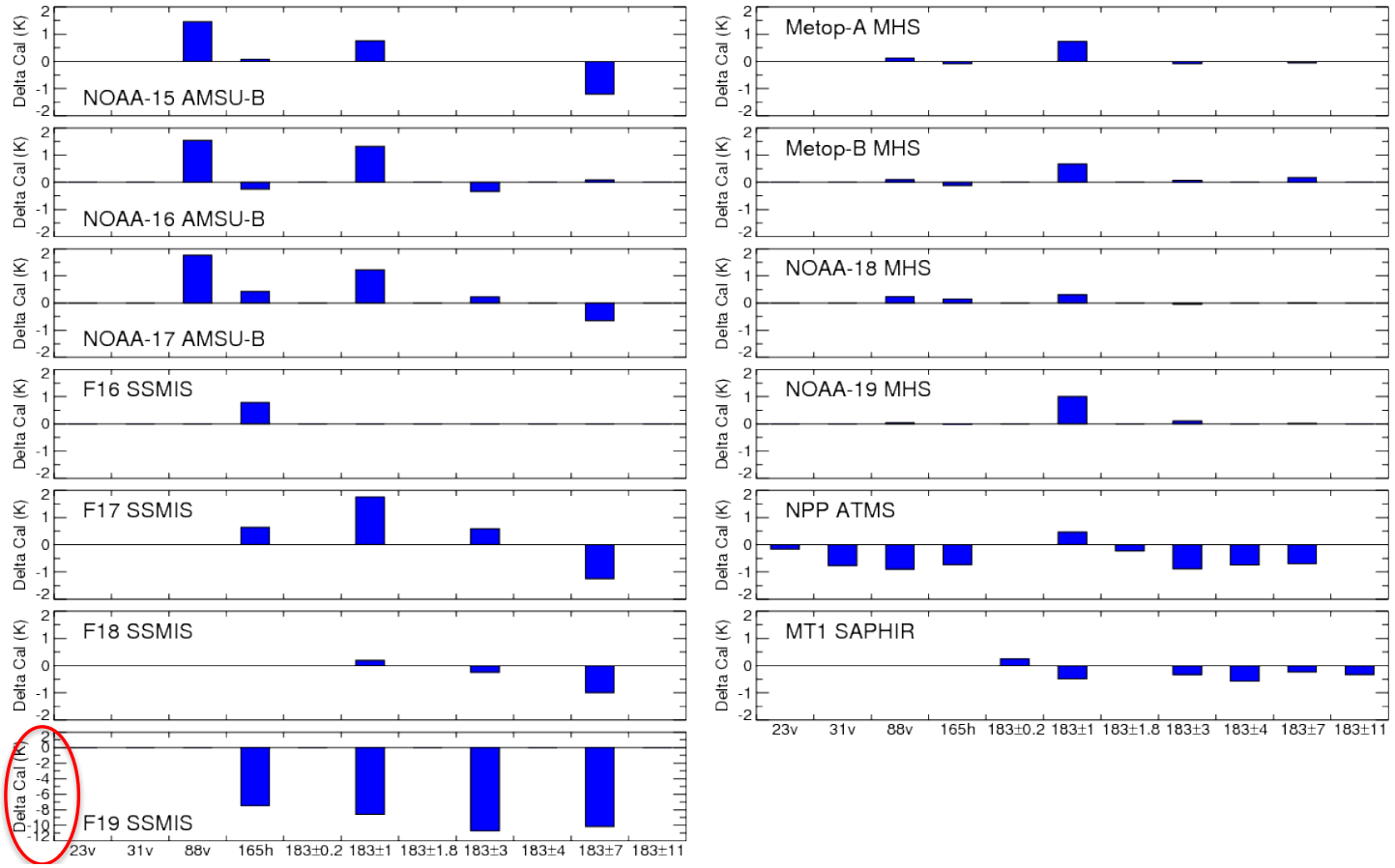
Conical-Scanning Imagers



Blue: Cold ocean scenes, Red: warm vegetated scenes

TRMM/GPM Radiometers Calibration Differences

Cross Track Scanning Water Vapor Sounders



XCAL Priorities and Plans

- **Constellation Changes/Additions**
- **Quantify Uncertainties and Assess Impacts**
- **Improvements to intercalibration techniques**
- **Documentation (Full Transparency)**

Constellation Changes/Additions

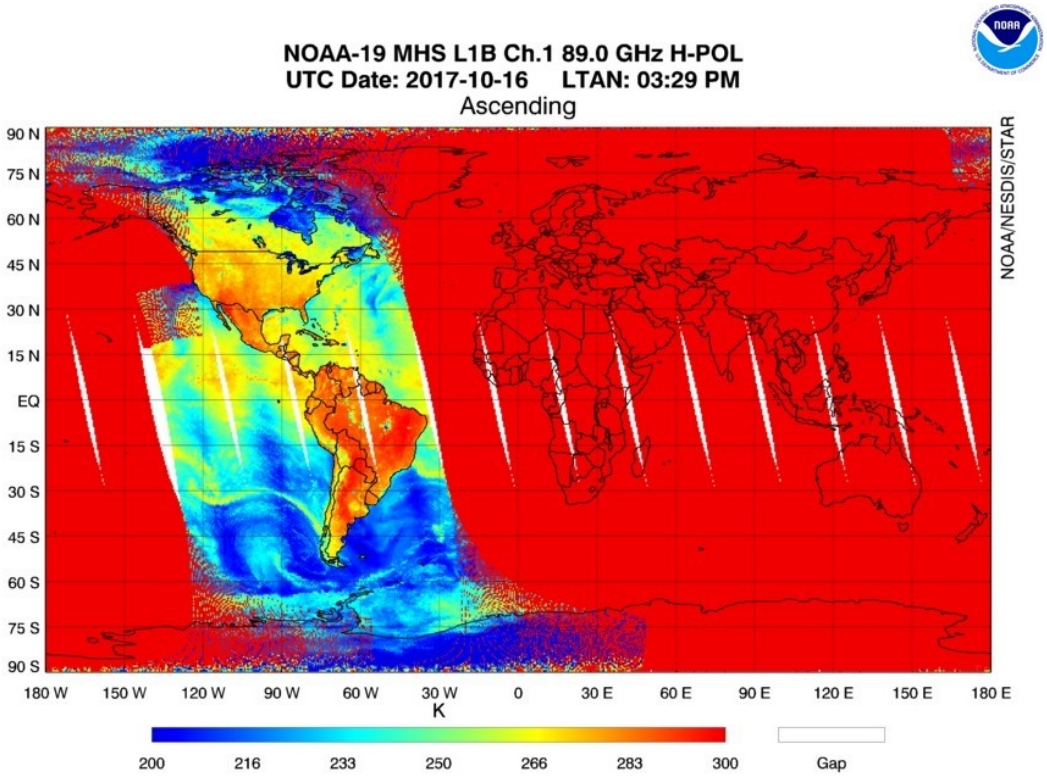
1. **Instrument monitoring/response to channel failures and/or calibration issues**
   - Emphasis on maximizing data availability for IMERG while flagging/removing bad data!
   - Examples
     - NOAA19 MHS failure (anomaly on Oct 9th, subsequently turned off)
     - DMSP F16 SSMIS 183 GHz channels (flagged, set to missing 1 Dec 2013, resumed 26 Aug 2015)
     - DMSP F17 SSMIS 37 GHz V-Pol channel (flagged: 5 Apr – 18 May 2016, 3 Aug 2016 forward)

2. **New/additional sensors**
   - JPSS1 ATMS: Launch scheduled for 10 Nov 2017
   - MetOp-C MHS: Sep 2018 launch
   - Incorporate reprocessed WindSat data record (Feb 2003 to present)
   - Pre-TRMM DMSP SSM/I sensors starting with F08 in July of 1987

3. **Updated calibration corrections**
   - DMSP SSMIS: emissive reflector, solar intrusions, thermal issues, etc.
   - AMSR2 nonlinearities
   - AMSU-B: Time-dependent corrections, more precise quality flagging, cross-track biases

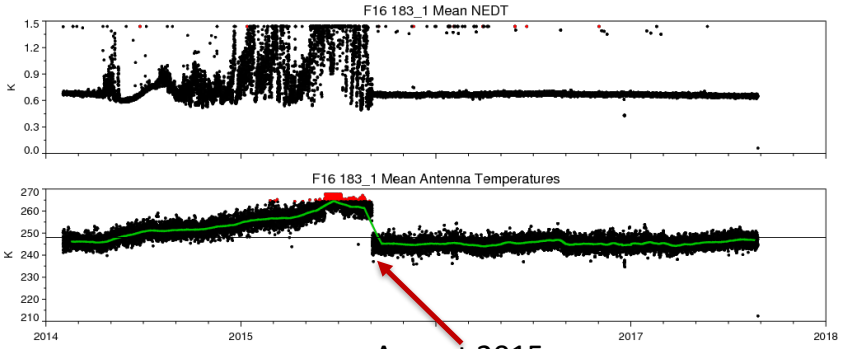
NOAA-19 MHS

16 October 2017



DMSP F16

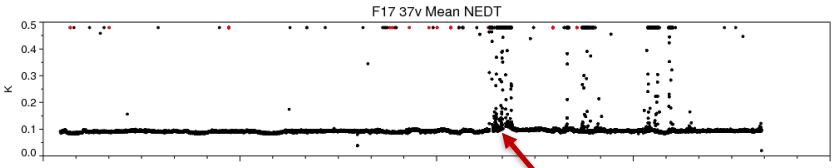
183±1 GHz, NEΔT and Mean Ta



August 2015

DMSP F17

37 GHz V-Pol, NEΔT



April 2016

Quantify Uncertainties and Assess Impacts

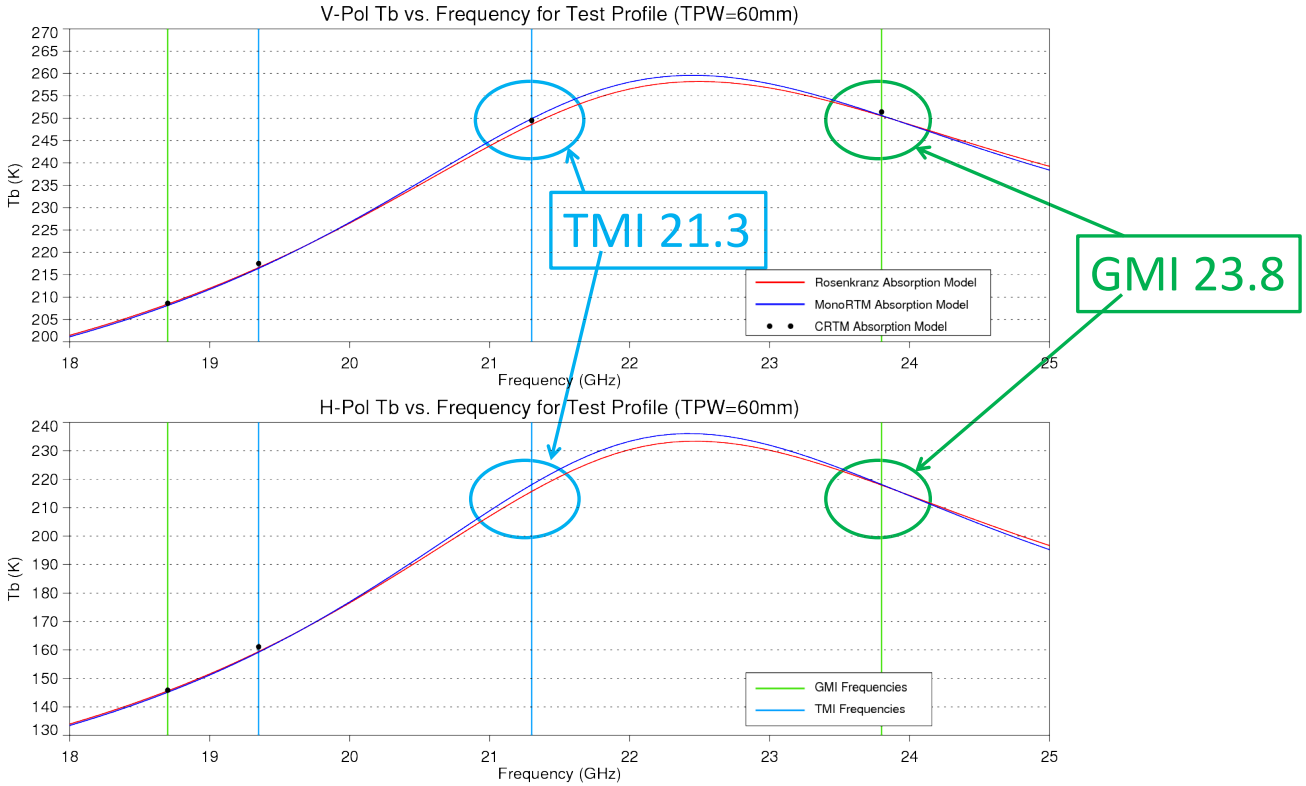
1. **Quantify residual uncertainties by instrument/channel**
   - Sources of uncertainty
     - Radiative transfer models
     - Geophysical parameters (model analysis/retrievals)
     - Sampling
     - Instrument
   - Considerations
     - Instrument issues: Emissive reflector, solar intrusions, antenna pattern/spillover, etc.
     - Channel differences vs. reference (frequency, polarization, cross-track vs. conical, view angle, etc.)

2. **Assess differences in models/parameters on simulated Tb and/or clear-sky retrievals**
   - Radiative transfer models
     - Atmospheric absorption
     - Ocean surface emissivity
     - Instrument spectral response
   - Geophysical parameters (model analyses and retrievals)
   - View angle (i.e. Earth Incidence Angle)

3. **Coordinate/work with algorithm developers**

XCAL TMI/GMI Calibration Differences

Radiative Transfer Model Dependency



Improvements to Intercalibration Techniques

1. **Updated geophysical parameters**
   - Implement/assess new reanalysis products: ERA5, MERRA2, …
   - Improved retrievals

2. **Additional calibration targets and/or surfaces**
   - Desert scenes for warm-target calibration
   - High-latitude vegetated scenes

3. **Channels without GMI/MHS equivalent**
   - AMSR 23H

4. **RFI flagging**

Summary

- **GMI is extremely well calibrated and stable**, providing an ideal calibration reference for the constellation radiometers. Potentially an excellent absolute calibration reference!
- GPM V05 reprocessing (May 2017)
  - **Calibration reference standard: GMI V05**
  - Changes to GMI calibration, primarily low frequency channels
  - Level 1C Tb data available for GPM constellation radiometers
- TRMM reprocessing (October 2017)
  - Significant TMI V8 calibration updates
  - **TMI/GMI provides high-quality reference dataset (Dec 1997 to present)**
  - Intercalibrated to GMI V05
  - Includes constellation sensors back to December 1997
- DMSP SSM/I reprocessing (Late 2018)
  - DMSP F08, F10, F11 and early F13, F14
  - July 1987 forward
- Future Sensors (~6 months after operational release)
  - JPSS1 ATMS (10 Nov 2017)
  - MetOp-C (Sep 2018)
  - MetOp SG (2021)

XCAL Plans/Priorities

1. Constellation changes/additions
   - Instrument monitoring/response to channel failures and/or calibration issues
   - New/additional sensors
   - Updated calibration corrections
2. Quantify uncertainties and assess impacts
   - Quantify residual uncertainties by instrument/channel
   - Assess differences in models/parameters on simulated Tb and/or clear-sky retrievals
   - Coordinate/work with algorithm developers
3. Improvements to intercalibration techniques
   - Updated geophysical parameters
   - Additional calibration targets and/or surfaces
   - Channels without GMI/MHS equivalent (i.e. AMSR 23H)
   - RFI flagging
4. Documentation